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USE OF ERTS DATA FOR MAPPING SNOW COVER IN THE WESTERN UNITED STATES

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16. Abstract

The purpose of this investigation is to evaluate the application of ERTS data for mapping snow cover. Data have been analyzed primarily for two test sites, the Central Arizona Mountains and the Southern Sierra Nevada in California. The results of the data analysis completed through this reporting period indicate that snow extent can be mapped from ERTS imagery in more detail than is depicted on aerial survey snow charts. For the areas tested, the agreement between the percentage snow cover as determined from ERTS data and from aerial survey snow charts is of the order of 5% for most cases. Moreover, it appears that although small details in the snowline can be mapped better from higher-resolution aircraft photographs, boundaries of the areas of significant snow cover can be mapped as accurately from the ERTS imagery as from the aircraft photography.

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PREFACE

The purpose of this investigation is to evaluate the application of ERTS data for mapping snow cover, primarily in the mountainous areas of the western United States. The specific objectives are to determine the spectral interval most suitable for snow detection, to determine the accuracy with which snow lines can be mapped in comparison with the accuracies attainable from other types of measurements, and to develop techniques to differentiate reliably between snow and clouds and to understand the effects of terrain and forest cover on snow detection.

The results of the data analysis completed through this reporting period indicate that snow extent can be mapped from ERTS imagery in more detail than is depicted in aerial survey snow charts. In the Salt-Verde Watershed in Arizona, the agreement between the percentage of the area snow covered as measured from the ERTS data and from aerial survey charts is generally well within 10%. In nearly all of the areas in which grater discrepancies occur, the differences can be explained by changes in snow cover during the interval between the two observations. In the southern Sierra Nevada in California, the agreement between ERTS data and aerial survey charts is of the order of 5% in all cases except one. Moreover, it appears that although small details in the snowline can be mapped better from higher-resolution aircraft data, boundaries of the areas of significant snow cover can be mapped as accurately from the ERTS imagery as from the aircraft photography. In the Arizona and California test sites, useful snow cover information could be derived from ERTS data on 70 to 80% of the cycles during the past winter and spring seasons. Thus, in these two areas, cloud obscuration does not appear to be a serious deterrent to the use of satellite data for snow survey.

1. INTRODUCTION

1.1 Purpose and Objectives

The purpose of this investigation is to evaluate the application of ERTS data for mapping snow cover, primarily in the mountainous areas of the western United States. The specific objectives are to determine the spectral interval most suitable for snow detection, to determine the accuracy with which snow lines can be mapped in comparison with the accuracies attainable from other types of measurements, and to develop techniques to differentiate reliably between snow and clouds and to understand the effects of terrain and forest cover on snow detection.

The snow extent mapped from the ERTS imagery is being correlated with standard snow measurements, aerial-survey snow charts, and aerial photography for both mountainous and flat terrain within the United States. The study is being concentrated primarily in two geographic areas, the souther Sierra Nevada in California and the Salt-Verde Watershed in Arizona. Mountain snow accumulations are of significant hydrologic importance in each of these areas. Data are also being examined for the Upper Columbia Basin in northern Idaho and Western Montana and for the Black Hills area of the Missouri River Basin.

Snow cover is a water resource for which spacecraft observation holds great promise. The results of this study will provide the hydrologist with interpretive techniques that will enable data from future operational satellite systems to be used to map snow on a more cost-effective basis.

1.2 Summary of Work Performed During Reporting Period

During the period of performance since the previous progress report (Type I report, 18 May), analysis of data had continued for the two geographic areas of primary interest, the Salt-Verde Watershed and the Southern Sierra Nevada. ERTS black and white imagery covering much of the Salt-Verde Watershed on three additional dates, 26 March, 13 April, and 2 May, have been received, as well as color composite data for two earlier dates, 21 November and 19 February. The snow extent mapped from the March and April ERTS data has been correlated with aerial survey snow charts for the nearest dates available. The March data are also being compared with aircraft photography taken on 16 March by the NASA/ARC Earth Resources Aircraft Project (ERAP).

Data analysis is in progress for ERTS imagery covering the southern Sierra Nevada on 25 February, 14-15 March, 19-20 April, 7-8 May, and 26 May. The April and May data are of particular interest because aerial snow survey charts are available for nearby dates, 27 April, 11 May, and 22 May, respectively. The ERTS imagery for 25 February is being compared with ERAP support data collected five days earlier. Color composite data have been requested for the Sierras, but have not yet been received from the NDPF.

Analysis of ERTS imagery covering portions of the Upper Columbia Basin and the Black Hills area of the Missouri River Basin are also in progress. Although more limited than the analyses being performed for the two areas of primary interest, the analysis of data for these two geographic areas will be especially useful for evaluating the effects of forest cover and clouds on snow detection.

The results of the investigation to date for each geographic area are described in more detail in Section 2 of the report.

2. MAIN TEXT

2.1 Salt-Verde Watershed

The 1972-73 winter season produced a record snowpack accumulation in the Salt-Verde Watershed in Central Arizona. Precipitation for the October through April period was much above normal, and the snowpack at its maximum in early April was estimated to be as much as 500% of normal in the Verde River Watershed and 300% in the Salt. At one location a snow depth of 132 inches with a water content of 52 inches was measured; normally, the maximum water content is about 10 inches. The April issue of Water Supply Outlook (published by the National Weather Service) gives a runoff forecast for the Verde of nearby 400% of the 1953-1967 average and for the Salt of more than 350%. Obviously, throughout this past winter-spring season, snow hydrology was a vital concern in Arizona water management programs.

2.1.1 ERTS Data Sample and Analysis Procedures

Snow extent for at least a portion of the Salt-Verde Watershed can be mapped from imagery for seven of the ten ERTS cycles between mid-November 1972 and early May 1973. For each cycle the eastern third of the watershed is covered on one day and the remaining part (with some overlap) on the following day. On one occasion (26 December) most of the area is cloud-free, but the imagery is not of useable quality. Thus, even in a year with much above average precipitation, the central Arizona area is sufficiently cloud-free that useful snow information can be derived on 80% of the ERTS cycles.

The dates for which ERTS imagery has been analyzed are given in Table 1. In addition to the black and white data, color composite data have been requested for five of the dates; so far, however, only two of the color composites have been received. The dates for which aerial survey snow charts are available are also given in Table 1. The methods used to compile these charts were described in a previous progress report (Type II report, February 1973). It should be noted that in some instances an interval of several days exists between the time of the ERTS data and the aerial survey chart. During the snowmelt season, however, aerial surveys were flown frequently; therefore, copies of charts nearer the dates of the ERTS data

TABLE 1

DATA SAMPLE FOR SALT-VERDE WATERSHED

Date of ERTS Imagery (1972-1973)	Date of Aerial Survey Snow Chart (1972-1973)
21 November	14 November
14 January	12 January
1 February	2 February
18-19 February	15 February
26 March	3 April *
13 April	6 April *
2 May	None *

* Aerial surveys were also flown on 26 March, 12 April, and 4 May. Copies of these charts have been requested from the Salt River Project Office.

have been requested from the Salt River Project office in Phoenix.

As described in previous progress reports, the MSS-5 (0.6-0.7 μm) spectral band has been found to be the most useful for detecting and mapping snow. In this band snow can be distinguished from cloud through a number of interpretive keys. Because the scale of the 9.5 inch ERTS prints is the same as the scale of the aerial survey snow charts (1:1 million), transfer of the snow extent mapped from the ERTS image to the aerial survey base map can be easily accomplished. For each case, an enlarged ERTS print (scale 1:500,000) has also been prepared. Although the enlarged prints are useful for interpreting small scale features, no significant differences have been found between the reprocessed and original prints. The effects of mountain shadows, which can be a problem in the Sierra Nevada (see Section 2.2.1), do not seem to be as much of a problem in the Salt-Verde Watershed area. Maps showing the snow extent derived from ERTS data and as depicted on the aerial survey charts are shown in Figures 1-4. A change in snow extent over a one-day period mapped in the area of orbital overlap is shown in Figure 5. Maps for the cases during the spring season are not shown, because the most appropriate aerial survey charts have not yet been received.

2.1.2 Comparison Between ERTS Data and Aerial Survey Snow Charts

The comparative maps shown in Figures 1-4 indicate that more detail in the snowline can apparently be mapped from the ERTS data than can be mapped by the aerial observer. In general, however, the locations of the snowlines are in good agreement, particularly in the Verde Watershed west of about 111°W. In nearly all areas in which a discrepancy occurs, the aerial survey chart depicts a greater snow extent than is mapped from the ERTS imagery. In some cases, as discussed in previous progress reports, this difference can be explained by melting that occurred during the interval between the observations; in the November case, for example, much of the light snow cover probably melted during the seven-day period. In Figure 5, an example of snowmelt that occurred over a 24-hour interval just north of the Salt Watershed is shown. The apparent snowmelt mapped from overlapping ERTS orbits is substantiated by the reported snowfall at Winslow; at that station four inches of snow fell on 16 and 17 February, but subsequently melted by the 18th.

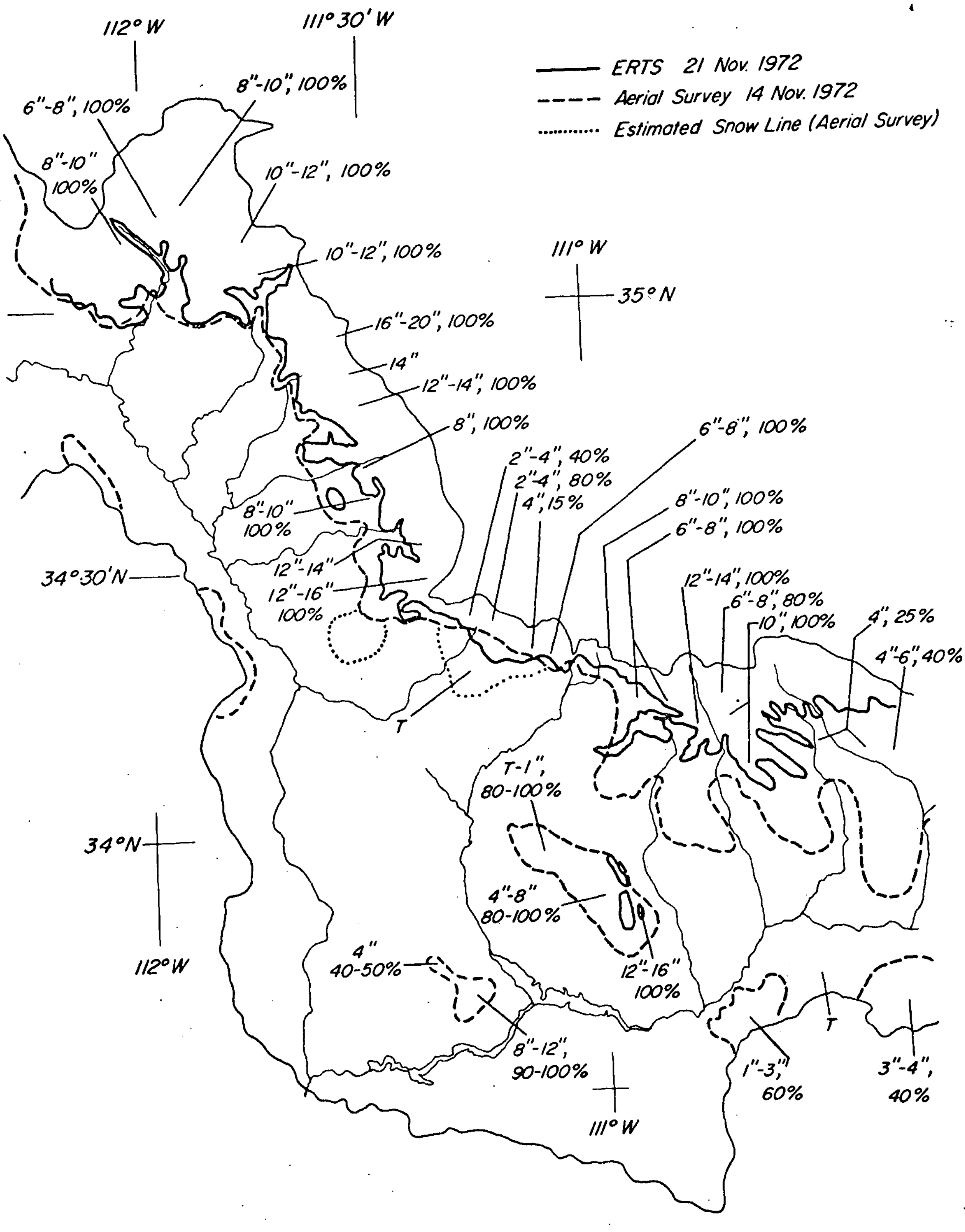

Figure 1 Comparison between snowline mapped from ERTS MSS-5 image and that depicted on aerial survey snow chart, Salt-Verde Watershed, Arizona, November 1972.

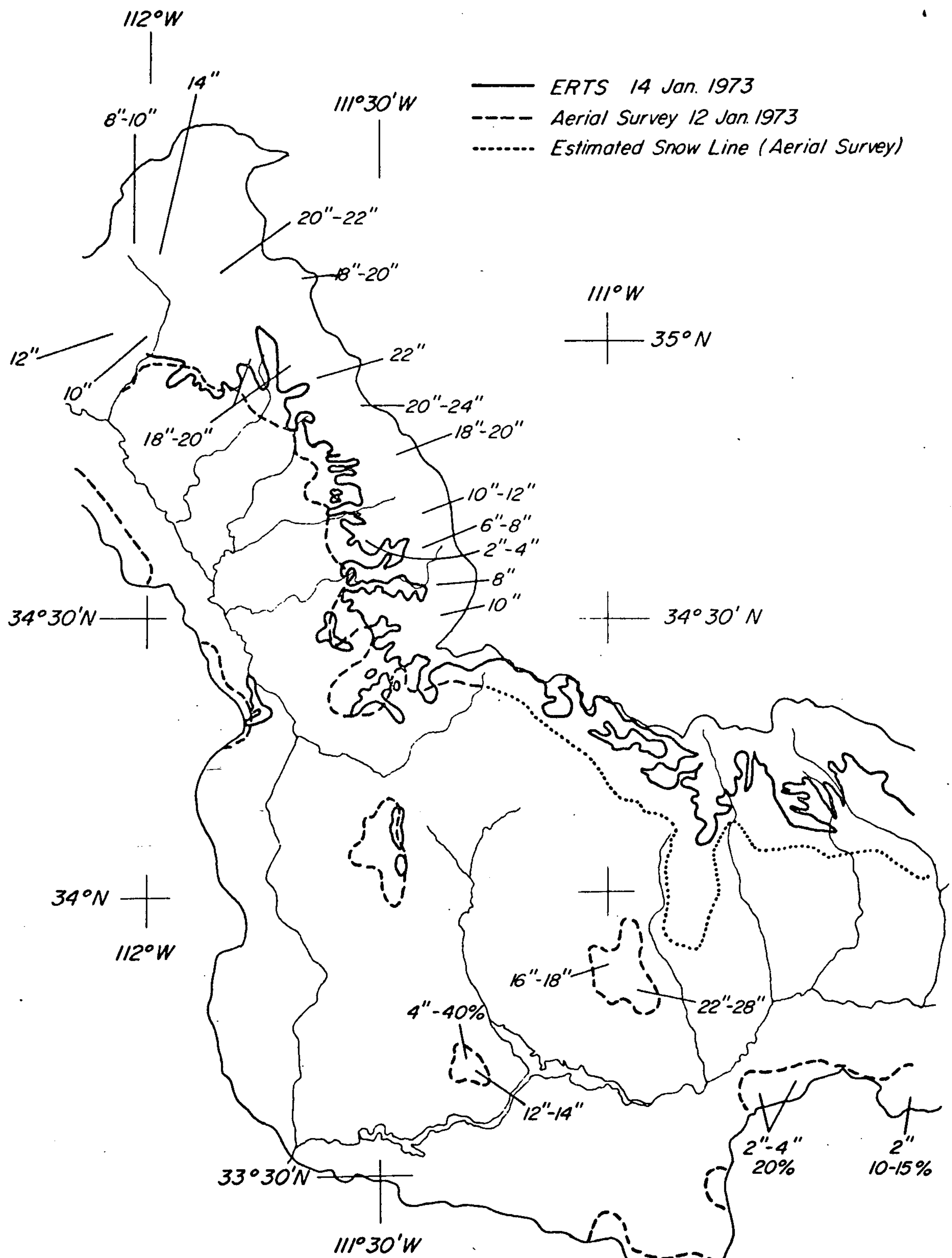

Figure 2 Comparison between snowline mapped from ERTS MSS-5 image and that depicted on aerial survey snow chart, Salt-Verde Watershed, Arizona, January 1973.

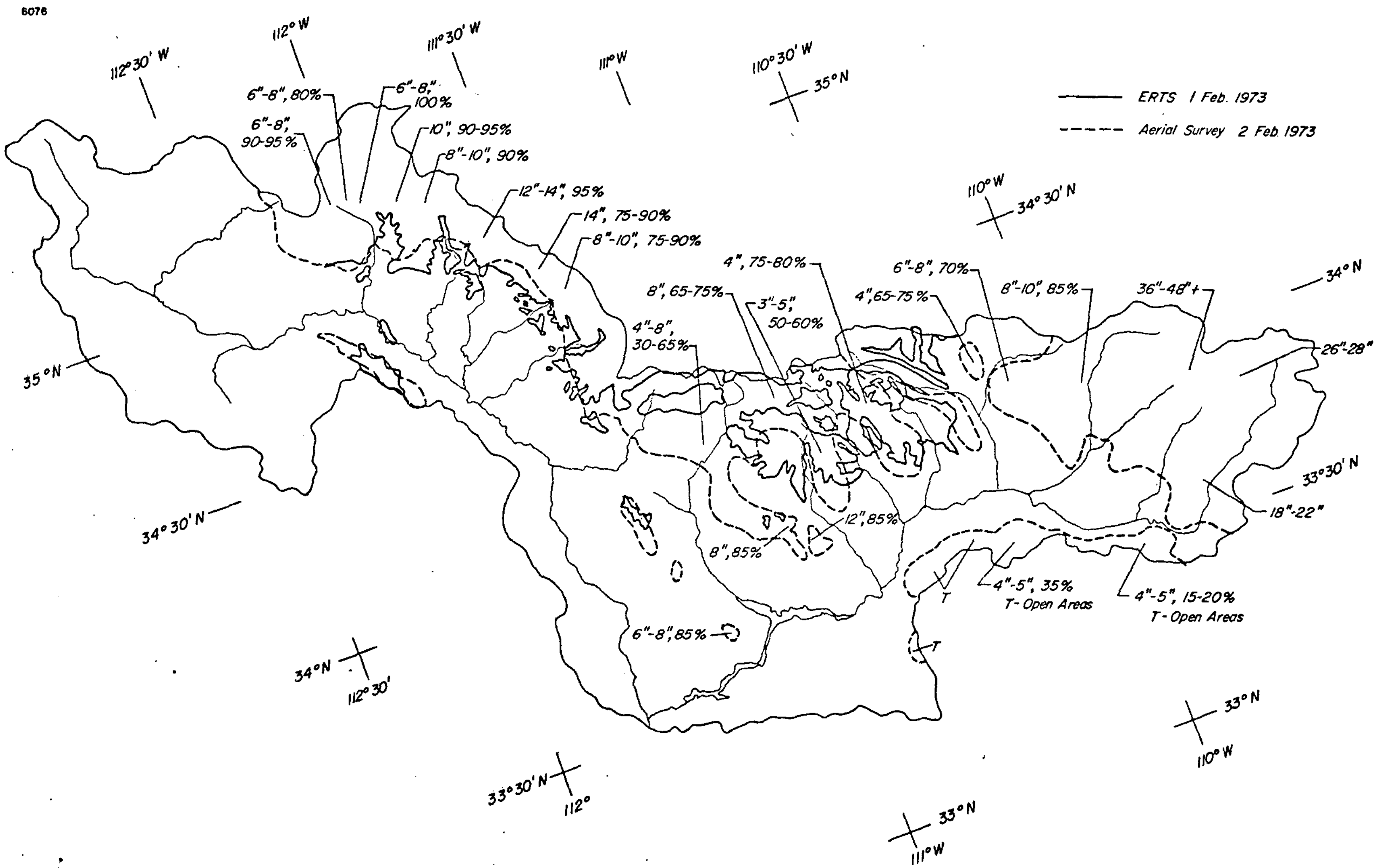

Figure 3 Comparison between snow line mapped from ERTS MSS-5 image (ID 1193-17330) and that depicted on aerial survey snow chart, Salt-Verde Watershed, Arizona, early February. Eastern part of watershed was not covered in the ERTS image.

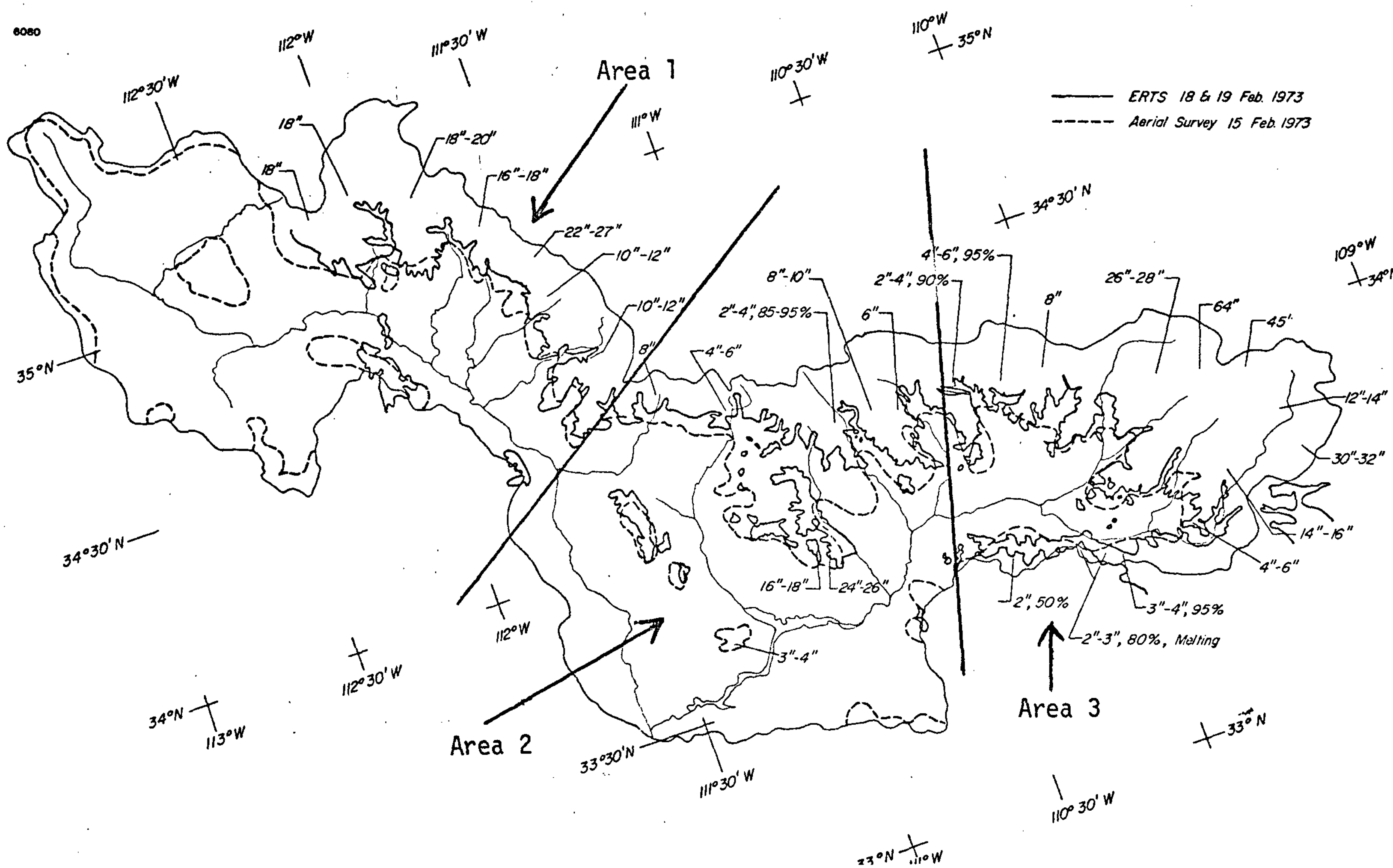

Figure 4 Comparison between snow line mapped from ERTS MSS-5 images (ID 1210-17273 and 1211-17332) and that depicted on aerial survey snow chart, Salt-Verde Watershed, Arizona, mid-February. The eastern part of the area was covered on 18 February and the western part a day later.

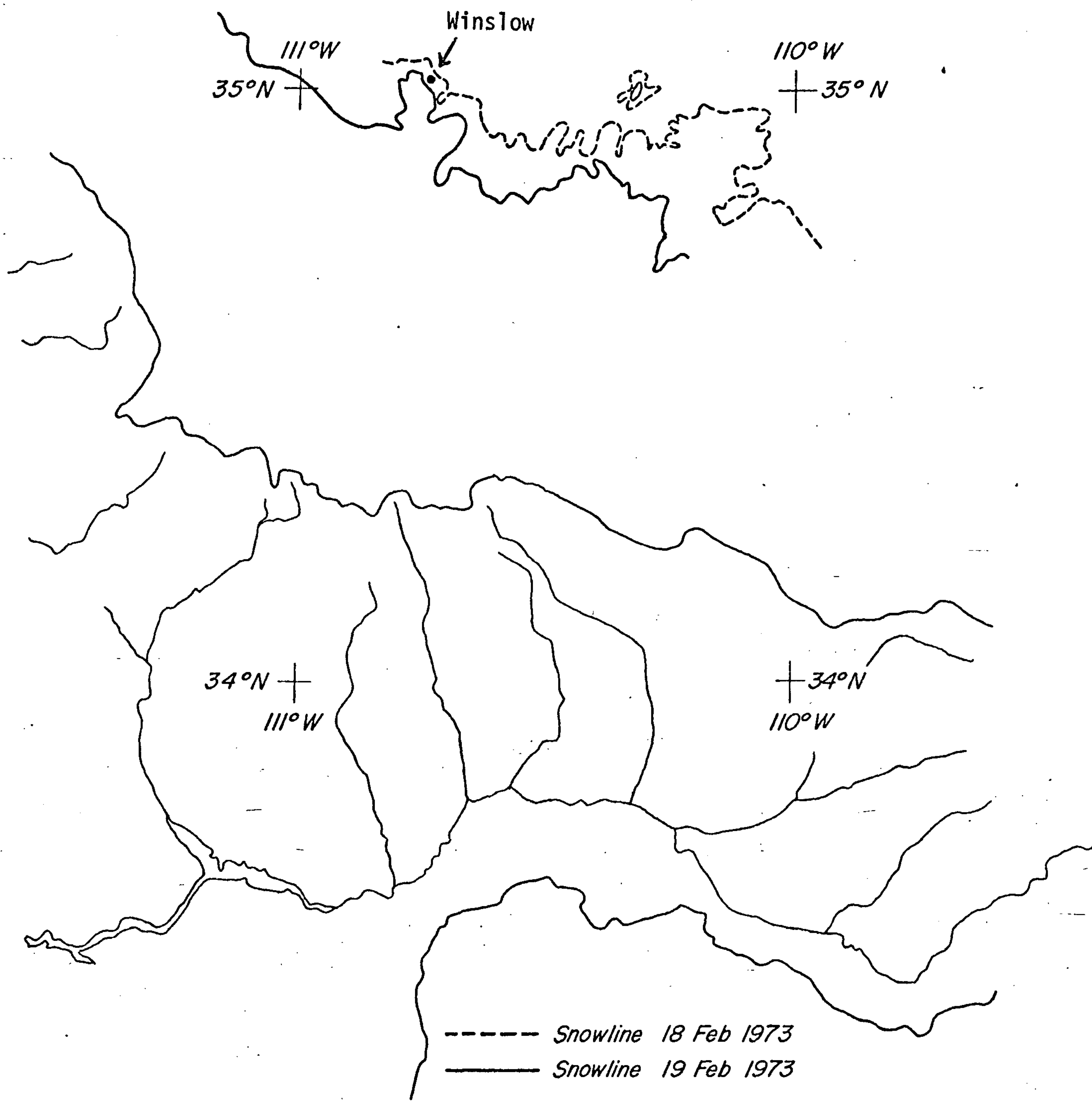

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Figure 5 Snow lines mapped from overlapping ERTS MSS-5 images (ID 1210-17273 and 1211-17332) on 18 and 19 February. Change in snow line position indicates that snow melt occurred during the 24-hour interval.

Because the most appropriate aerial survey snow charts for the spring cases have not been received, only a tentative comparison can be made with the snow extent mapped from ERTS images on 26 March, 13 April, and 2 May. In the rather limited portion of the eastern part of the Watershed that is cloud-free on 26 March, the ERTS image indicates considerably less snow than is depicted on the chart for 3 April. A check of the records reveals that considerable snowfall did occur during the period, which could explain the difference. McNary, for example, received a total of 36 inches of snow. Despite a seven-day interval between the aerial survey chart and the 13 April ERTS image, the agreement is very close for that case.

To obtain a quantitative evaluation of the differences between the ERTS data and aerial survey charts, the percentage of snow cover was computed. The total Salt-Verde Watershed was divided into three areas, the northwestern portion in which the agreement appeared to be the best, the central portion, and the eastern portion (the approximate areas are shown in Figure 4). The boundaries of the areas vary slightly from case to case because of variation in the exact area covered by ERTS and cloud conditions. The percentage of the area snow covered was then measured for each section using a compensating polar planimeter. The resulting percentages are shown in Table 2.

Overall, the mean difference in the percentage of the watershed snow covered is 8%. The mean difference for Area 1 is 6% and for both Areas 2 and 3, 10%. In every measurement taken, the percentage of the area snow-covered mapped from ERTS is less than the percentage measured from the aerial survey snow chart. The greatest difference is 18%, measured in Area 2 in the November case and in Area 3 in the March case. In both cases, as explained above, a significant change in snow cover probably occurred between the time of the ERTS data and the aerial survey.

2.1.3 Comparison Between ERTS and ARAP Data

On 16 March aircraft support data for the central Arizona mountains were collected by the NASA/ARC Earth Resources Aircraft Project. The high-altitude aircraft data consist of three rolls of 70 mm black and white photography (plus X-2402 film in the 0.475-0.575 μm and 0.580-0.680 μm spectral bands, and infrared aerographic -2424 film in the 0.690-0.760 μm band), one roll of 70 mm color photography (aerochrome infrared -2443 film

TABLE 2

COMPARISON BETWEEN SNOW EXTENT MAPPED FROM ERTS AND AERIAL SURVEY SNOW CHART, SALT-VERDE WATERSHED

Area 1 = Western Portion of Watershed
Area 2 = Central Portion of Watershed
Area 3 = Eastern Portion of Watershed

DATE ERTS	DATE Aerial Survey	Area Analyzed	ERTS % of Area Snow-covered	AERIAL SURVEY % of Area Snow-covered	DIFFERENCE Aerial Survey Minus ERTS
21 Nov.	14 Nov.	Total	19	33	14
		Area 1	36	46	10
		Area 2	9	27	18
14 Jan.	12 Jan.	Total	19	26	7
		Area 1	32	40	8
		Area 2	7	19	12
1 Feb.	2 Feb.	Total	22	29	7
		Area 1	41	43	2
		Area 2	13	21	8
18-19 Feb.	15 Feb.	Total	39	48	9
		Area 1	48	53	5
		Area 2	20	30	10
		Area 3	67	74	7
26 Mar.	3 Apr.	Area 3	32	50	18
13 Apr.	6 Apr.	Total	29	33	4
		Area 2	11	15	4
		Area 3	46	51	5
MEAN	5 cases	Total	-	-	8
	4 cases	Area 1	-	-	6
	5 cases	Area 2	-	-	10
	3 cases	Area 3	-	-	10

in the 0.510-0.900 μm spectral band), and one roll of 9 inch color photography (same film as above). The 70 mm photography is from a Vinten sensor with a 1.75 inch focal length, and the 9 inch photography is from an RC-10 sensor with 6 inch focal length. The film was first examined to verify the locations of the flight paths and the cloud conditions. Subsequently, two segments, one crossing the Flagstaff area in the Verde Watershed and the other crossing the Mt. Baldy area in the eastern Salt Watershed, were selected for further analysis. For these segments, enlarged 8x10 inch positive prints were prepared from the 70 mm 0.580-0.680 μm and 0.690-0.760 μm bands. The individual frames were then mosaiced to cover the flight path segment of interest.

The ERTS data nearest the time of the aircraft flight are for 26 March, ten days later. During the intervening period, substantial snowfall did occur (about 20 inches at Flagstaff and 13 inches at McNary); however, the snow on the ground at both stations was less on the 26th (25 and 4 inches, respectively) than on the 16th (30 and 18 inches, respectively). The most recent previous snowfalls at both stations were on 14 March, two days before the aircraft flight, and on 23 March, three days before the ERTS passage.

The comparative analysis of these data is in progress. The primary step has been to identify corresponding features in the aircarft photographs and the ERTS imagery, realizing the different scales (especially with regard to the RC-10 film) and possible changes in snow cover. Stereo-viewing of the RC-10 film has been found useful for identifying forest effects and shadows associated with north-facing slopes. Careful mapping of snow boundaries and other features is being accomplished.

The preliminary results of the analysis indicate that no significant difference in snow detection is apparent between the 0.580-0.680 μm and 0.690 - 0.760 μm aircraft data products. In comparison with ERTS data, detailed snow features that cannot be detected in the ERTS imagery can be seen in the aircraft photography. However, it appears that all significant snow cover (i.e., substantial snow cover, not small amounts such as might be found along small topographic features) can be detected in the ERTS imagery. Further analysis to determine more precisely the scales of the features that can be mapped will be undertaken.

2.1.4 Multispectral Data Analysis

ERTS Color composite positive transparencies have been received for 21 November and 19 February and are on request for three other dates. Although a thorough evaluation of the advantages of the color products must await additional data, examination of the initial transparences indicates that the color product may have some advantages for snow detection and mapping. In the color transparencies, water features such as lakes, reservoirs, and rivers can be more readily identified, as can vegetation areas and the locations of the treeline. In forested areas, snow appears to be more discernible than it is in the single-band data products. Furthermore, snow can be more easily distinguished from highly-reflective snowfree rock surfaces and can be mapped more easily in shadow areas in the color composite data.

Further investigations of multispectral data products, including the color composites and the individual spectral bands, will be performed. It has not yet been determined whether the near-IR band (MSS Band 7, 0.8-1.1 μm) can provide additional information on snow conditions. The data from the spring season will be examined carefully to determine whether melt areas, which are indicated on the aerial survey snow charts, can be discerned through a comparison of the visible and near-IR reflectances.

2.2 Southern Sierra Nevada

The snowpack in the southern Sierra Nevada was also above normal this past season. The California Department of Water Resources Bulletin, Water Conditions in California, reports that early in the winter the snowpack that had accumulated by late December was depleted at lower elevations and reduced at higher elevations by warm storms during early January, but subsequent storms and colder weather brought the snow pack to above normal by the first of February. A relatively wet February raised the water content of the snow pack, and the continuation through March of cool, wet weather boosted the snow water content to even greater amounts in most watersheds. On the first of April, the snow water content at mid-elevations of the Kern, Kaweah, Tule, and Kings was greater in percentage of normal than at the higher elevations. In fact, two snow courses in this area had water contents that exceeded the maximum water content ever recorded. Although precipitation was below normal during April, the snowpack water content was still well above normal in early May. Snow course measurements made about the first of May indicated a snowpack water content as high as 315 percent of average in the Tule River Basin. On this date the Water Supply Outlook forecast the water-year streamflow for the San Joaquin drainage area to be 100 to 150 percent of average.

2.2.1 ERTS Data Sample and Analysis Procedures

The dates for which ERTS data have been analyzed for the southern Sierra Nevada are given in Table 3. In the ERTS orbital configuration the Kern Basin is covered on one day and the Kings Kaweah, and Tule (and part of the Kern) on the following day. Because of cloud obscuration, the entire four-basin area was not mapped in each case; however, during the period from early December throught late May, a major part of the area was sufficiently cloud-free to be mapped on seven of the ten ERTS cycles.

Aerial Survey snow charts depicting the snow extent in the four-basin area were prepared by the Corps of Engineers on 27 April, 11 May, and 22 May. These charts are at a scale of 1:1 million, the same as the 9.5 inch ERTS prints. Aircraft data were also collected over parts of the southern Sierras in support of the ERTS project by NASA/ARC on 20 February. Snow cover measurements from the California Cooperative Snow Survey Program are available for the first of each month, from February to May.

The analysis procedures for the ERTS data are similar to those described in the previous section for the Arizona test site. The snow extent has been mapped from the ERTS images onto 1:1 million scale base maps. The snowline elevation has been measured directly from the base maps through comparison with superimposed contours. The percentage of each basin snow-covered has also been determined from the planimetered snow extent; using these values, the equivalent snowline has been derived from area vs. elevation curves supplied by the Sacramento River Forecast Center.

Because of a problem with mountain shadows, discussed in earlier progress reports, the snow line elevation for four cases (21 October, 27 November, 2 January, and 20 January) has been mapped both from the original 9.5 inch prints and from reprocessed enlarged prints. The enlarged prints, which are at a scale of about 1:500,000, were processed from the 70 mm negatives using various exposure times in order to bring out more detail in the dark shadow

TABLE 3

ERTS DATA SAMPLE FOR SOUTHERN SIERRA NEVADA

Date		River Basins Covered
16 September 1972	-	Kings, Kaweah, Tule
21 October 1972	-	Kaweah, Tule, Kern
26-27 November 1972	-	Kings, Tule, Kern
2 January 1973	-	Kings, Kaweah, Tule
20 January 1973	-	Kings, Kaweah, Tule
25 February 1973	-	Kings, Kaweah, Tule
14-15 March 1973	-	Kings, Kaweah, Tule, Kern
20 April 1973	-	Kings
8 May 1973	-	Kings, Kaweah, Tule
26 May 1973	-	Kings, Kaweah, Tule

areas. A comparison of the prints has revealed that in many instances the shadow effects are reduced through the reprocessing; in some areas, snow - no snow boundaries that were obscured in the original prints can be detected. In the 20 January case, the equivalent snowline derived from the reprocessed print is slightly higher (mean value of 400 ft.) than that derived from the original prints. For the other cases, however, the equivalent snowlines from the reprocessed prints are substantially lower than those from the originals, the difference being as much as 1600 ft. in the Kings Basin for the 2 January case. The lower snowline elevation (4800 ft.) on 2 January seems more reasonable since snow cover is reported at stations as low as the 4700 ft. level on that date. Therefore, because of the apparent better snow definition and the more reasonable snowline elevation, the reprocessed enlarged prints were used for the above mentioned dates.

In some of the positive prints received recently from the NDPF, dark features are surrounded by an area of much brighter tone. In the 25 February print, for example, this "halo" effect is pronounced in the Mono Lake area. Since the halos are not apparent in the 70 mm negatives, new prints have been prepared for the data in question. It is presumed that the halo effect is due to the "dodged print" processing announced in the ERTS Investigators' Bulletin of 10 April.

2.2.2 Snowline Elevation Measured from ERTS Data

The snowline elevation determined from a direct comparison with a contour chart varies considerably within each river basin. The Kings River Basin was divided into three sections, and the mean elevation for each section was determined from a large number of data points. For the three cases from the spring season, the mean difference between the section with the highest snowline elevation and that with the lowest is 1400 ft. As a check, to determine whether the difference might be due to ERTS mapping inaccuracies, a similar procedure was followed with the three aerial survey snow charts for approximately the same dates. The mean difference for these charts is 1600 ft., somewhat greater than was found for the ERTS data. For both the ERTS and aerial survey data the differences are fairly consistent; in each instance the snowline elevation is highest in the eastern part of the basin, along the Middle and South Forks of the Kings River.

The snowline elevation determined directly as described above has been compared with the snowline elevation determined by measuring the percentage of the basin snow covered and referring to the area - altitude curve for the particular basin. In an earlier study using meteorological satellite photography, the snowline elevation for the Kings Basin was determined in this way (Barnes and Bowley, 1970: "The Use of Environmental Satellite Data for Mapping Annual Snow-Extent Decrease in the Western United States," Final Report for NOAA/NESS under Contract No. E-252-69(N)). Recently, the snowline determined from areal snow extent, or the equivalent snowline altitude (ESA), has been discussed further with regard to ERTS data (Meier, 1973: "Evaluation of ERTS Imagery for Mapping of Snowcover," paper presented at Symposium on Significant Results Obtained from ERTS-1, NASA/GSFC). In the Kings Basin, the mean absolute difference between the measured snowline and the ESA for nine cases is 336 ft. In five cases the ESA is higher than the measured elevation, and in four cases it is lower; the maximum difference is 890 ft. on 27 November, the ESA being higher than the measured elevation. In all cases tested, the ESA is between the maximum and minimum values measured directly. In the Kaweah Basin, the mean difference between the ESA and measured snowline is nearly 500 ft., with the ESA being lower in seven of the nine cases; similarly, in the Tule Basin the difference is about 500 ft., with the ESA being lower in six of the nine cases. In the Kern Basin, the difference is 140 ft. for three cases tested.

Because of the observed variation in the snowline elevation measured directly, which can be influenced significantly by small mapping errors, it is believed that the equivalent snowline altitude (ESA) is a more meaningful measurement with regard to the application of satellite data to snow mapping. The percentage snow cover and ESA for each river basin are shown in Table 4. Overall, the results seem reasonable, with the ESA lowering to the 3000 to 4000 ft. level in the mid and late winter. The lowering of the snowline during the interval from 2 to 20 January is substantiated by the reported snow amounts; at some stations the snow depth more than doubled during this period. On certain dates, however, the results do seem somewhat questionable; the snowline elevation appears too low in September and somewhat too high in the 25 February case.

In the September imagery, the interpretation of the snow extent is somewhat questionable, because the highly reflective area that could be mapped as being snow-covered coincides almost exactly with the higher ele-

TABLE 4

SNOW EXTENT WITHIN RIVER BASINS OF SOUTHERN SIERRA NEVADA MAPPED FROM ERTS DATA

	KINGS		KAWEAH		TULE		KERN	
DATE	%	ESA	%	ESA	%	ESA	%	ESA
16 Sept. 72	40	9000	23	8200	8	7400	-	-
21 Oct. 72	-	-	23	8200	15	6400	30	8200
26-27 Nov. 72	68	6600	-	-	16	6300	48	7000
2 Jan. 73	79	4800	45	6000	33	5800	-	-
20 Jan. 73	81	4500	78	3000	65	3100	-	-
25 Feb. 73	71	6300	45	6000	33	5800	-	-
14 Mar. 73	-	-	73	3400	50	4100	70	5400
15 Mar. 73	76	5500	64	4200	33	5100	-	-
20 Apr. 73	75	5700	-	-	-	-	-	-
8 May 73	64	7000	45	6000	16	6400	-	-
26 May 73	56	7800	38	6600	13	6600	-	-

% = Percentage of Basin Snow-Covered

ESA = Equivalent Snowline Altitude (in feet) vation area indicated on the topographic maps to be non-forested. Personnel in California involved in snow measuring activities are in general agreement that continuous snow cover would be unlikely during September, even at the highest Sierras elevations. It is possible, therefore, that the area of high reflectance includes bare rock as well as snow. In this instance, color composite data may be particularly useful for interpreting the snow extent. In later cases (26 November and 14 December), the brightest tones in the Kern Basin also fit closely with the non-forested areas, but a snow line can be identified at a lower elevation.

The February ERTS imagery will be reexamined, as will be the 14 and 15 March imagery. On the latter two dates, the Kaweah and Tule Basins are in the area of orbital overlap and, thus, are covered on each day. A comparison of the two images indicates significant differences in the apparent snow extent in certain areas. These images will also be reexamined to ascetain whether these apparent differences are real.

2.2.3 Comparison Between ERTS Data and Aerial Survey Snow Charts

The snow extent mapped from ERTS data is compared with the snow extent depicted on aerial survey charts for the three spring cases in Table 5. Because of cloud cover, the Kern Basin was not mapped. The results show that in every case except one the difference in percentages snow cover is less than 10%. The mean difference for the Kings Basin for the three cases is 5%, for the Kaweah 12.5%, and for the Tule 5.5%. The mean differences in the equivalent snowline altitude are 533, 1200, and 700 ft., respectively. For each case analyzed, the percentage snowcover determined from ERTS data is greater than that of the aerial survey chart; thus, the ESA determined from ERTS is lower than the ESA shown in the aerial survey chart.

As was pointed out in the discussion of the Arizona data, it appears that considerably more detail in the snowline can be mapped from ERTS imagery than is mapped by the aerial observer. The greatest discrepancy between the ERTS and aerial survey data occurs in late May in the Kaweah Basin, when the percentage snow cover is 18% greater for ERTS. A careful check of the geographic gridding of the image does not indicate an error that could account for the observed difference. A review of the image shows that certain areas, which are not depicted as being snow covered on the aerial

TABLE 5

COMPARISON BETWEEN ERTS DATA AND AERIAL SURVEY SNOW CHARTS FOR RIVER BASINS OF SOUTHERN SIERRA NEVADA

River Basin	ERTS Date 1973	ERTS %	ERTS ESA	Aerial Survey Date 1973	Aerial Survey %	Aerial Survey ESA	Difference (Aerial Survey-ERTS) %	Difference (Aerial Survey-ERTS) ESA
Kings	20 Apr.	75	5700	27 Apr.	69	6500	6	800
	8 May	64	7000	11 May	59	7500	5	500
	26 May	56	7800	22 May	52	8100	4	300
	MEAN	--	--	--	--	--	5	533
Kaweah	8 May	45	6000	11 May	38	6600	7	600
	26 May	38	6600	22 May	20	8400	18	1800
	MEAN	--	--	--	--	--	12.5	1200
Tule	8 May	16	6400	11 May	11	7000	5	600
	26 May	13	6600	22 May	7	7400	6	800
	MEAN	--	--	--	--	--	5.5	700

% = Percentage of Basin Snow-Covered

ESA = Equivalent Snowline Altitude (in feet) survey chart, appear to be definitely snow covered. Weather charts indicate that snow could have fallen during the interval between the observations, but this cannot be ascertained for certain until clinatological data for May can be acquired. This case will be reexamined in an attempt to resolve the apparent discrepancy.

2.2.4 Comparison Between ERTS and ERAP Data

Similar aircraft support data as were collected over the central Arizona Mountains were collected by the NASA/ARC Earth Research Aircraft Project (ERAP) over the southern Sierra Nevada on 20 February. Three segments of the flight cross areas covered in the ERTS imagery of 25 February. Parts of two of the segments are within the four-basin area, whereas the third is just northeast of that area. As with the Arizone data, enlarged prints have been made of the 0.580-0.680 μm black and white 70 mm frames, and stereo-viewing has been used with the 9 inch RC-10 photographs. For all segments of the flight path, however, the RC-10 color photographs are saturated over areas of extensive snow cover, and thus are not useful for analysis in most instances.

The segment northeast of the Kings River Basin crosses Mono Lake and the Owens River in the vicinity of Bishop. In both the aircraft and ERTS data, the snowline can be identified in the area north of Bishop indicated on the topographic chart to be an area of volcanic tableland essentially unvegetated. The snowline appears to be at about the 5000 ft. level, with little change having occurred during the five-day interval between 20 and 25 February. More detail in the snowline and same patchy snow south of the edge of the solid snow cover can be mapped from the aircraft data. However, that the edge of the area of significant snow cover can be mapped as precisely from ERTS as from the aircraft photography.

In another segment of the overflight, the area of the Courtright and Wishon Reservoirs in the northern Kings Basin can be identified in both the ERTS and aircraft data. The two reservoirs, which are frozen and snow covered, and the Lost Peak area in between appear very bright. The surrounding terrain consist of a mixture of open and forested terrain, appearing alternately bright and very dark in the aircraft photography. In the ERTS image, the larger bright areas can be identified whereas the smaller areas are integrated with the forested areas to produce a geay tone. It appears, therefore, that even though more detailed patterns can be identified in the aircraft data, the information content of the ERTS image with regard to mapping snow cover is equal to that of the higher resolution photography.

Processing of the aircraft data for the third segment, crossing the Kings Basin near the confluence of the Middle and South Forks of the Kings River, is in progress. In this immediate area, the RC-10 color film is not as badly saturated as in the other areas.

2.2.5 Multispectral Data Analysis

ERTS color composite data for several of the passes crossing the southern Sierras are on request, but have not yet been received. Analysis of the various bands of the black and white data products is in progress. In the September case, the bright area in the MSS-4 band cannot be detected in MSS-7. In the later cases, the snow line in most areas identifiable in the MSS-4 or -5 bands can also be identified in the MSS-7 band; however, the contrast between snow and non-snow is much lower in the near -IR than in the visible. The multispectral data for the spring cases have not yet been examined.

2.3 Upper Columbia Basin

A limited data analysis has been undertaken for the Upper Columbia Basin in nothern Idaho and western Montana. Because of the more frequent cloud obscuration in this region, a considerably smaller amount of useable ERTS data has been available than for the Arizona and California test sites. Moreover, in the entire Columbia Basin the snowfall during the past winter was well below normal, resulting in a below normal runoff. Because of the lack of substantial snow cover, in comparison with normal conditions and, in particular, with the exceptional snowfall of the two previous years, fewer areial snow survey flights were made by the Corps of Engineers during this spring. Therefore, a reduced amount of correlative data are available for use with the few cloud-free ERTS images.

An ERTS image on 21 January shows extensive snow cover in the area of the confluence of the Clearwater and Potlatch Rivers between Lewiston and Orafino, Idaho. The terrain in this general area consists of numerous narrow ridges and valleys, however, which produce shadow effects that make the precise mapping of snow difficult. As with the winter imagery in the

Sierras, the shadow problem is alleviated by reprocessing the images to a larger scale using a different exposure time.

In another ERTS image covering the same area on 8 February, the snow cover appears to have decreased considerably. A check of the climatological data summary for stations in the area indicates that snowmelt probably did occur during the period as the result of rather high temperatures. Imagery on 26 February indicates snow cover on only the higher elevations, and in imagery on 3 April very little snow cover can be identified.

ERTS data covering the Flathead Lake area in Montana on 19 April provide a good example of the problems of cloud obscuration that appear to be rather common in this region. In this imagery, the lower elevation terrain is essentially cloud-free; however, each mountain range, such as the Flathead Range south of the lake, is covered by cumuliform cloudiness. The extent of the clouds nearby coincides with the snow extent for this range, which can be detected in a few places through breaks in the cloud cover.

2.4 Black Hills Area

The Black Hills of South Dakota is a heavily forested area surrounded by open land. Because the forest limits are well-defined, this region presents a rather unique opportunity to investigate the effects of forest cover on the detection of snow in ERTS imagery. During this past winter, useable data were collected on at least five passes over the Black Hills, on 6 December, 11 and 29 January, 16 February, and 6 March. Imagery from these passes has been assembled, and snow cover maps for the nearest dates have been received from the Kansas City River Forecast Center. The initial examination of these images shows varying snow cover conditions, ranging from complete snow cover throughout the region on 11 January, to bare ground, except in the Black Hills area itself, on 6 March. The snow cover maps substantiate the conditons apparent in the imagery. Further investigation of the effects of forest cover is awaiting the receipt of ERTS color composite data that have been on request for some time.

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2.5 Practical Applications and Estimates of Costs and Benefits Resulting from the Use of ERTS Data for Snow Mapping

Discussions with personnel at user agencies involved in water supply management in Arizona, California, and the Pacific Northwest have indicated considerable interest in the results of the investigation of the application of ERTS data for snow mapping (the agencies and individuals are listed at the end of this section). The Watershed Specialist for the Salt River Project in Arizona, who is responsible for the aerial snow survey measurements, speaks enthusiastically about the mapping accuracies attainable from ERTS imagery. He points out that in at least one instance this past winter, a significant amount of snowmelt runoff was "wasted"; but, with better information on snow conditions, such as might have been provided by ERTS data, it is possible that a management decision could have been made so that the runoff could have been diverted to a power-generating station to produce "revenue" rather than simply being "wasted."

The costs involved in deriving snow extent maps from ERTS imagery appear to be very reasonable in comparison with current data collection methods. The flight time to survey the Salt-Verde Watershed is approximately five hours, with another hour or so needed to compile the snow chart. On the other hand, the snow extent can be mapped from an ERTS image covering nearly the entire Watershed area by an experienced analyst in about two hours. Eventual machine processing can be expected to reduce this time considerably.

The major drawbacks to the use of ERTS data as imput to an operational system are the availability of the data and the rate of repetitive coverage. To be useful operationally the data would have to be made available to the user within 24 hours. The rate of repetitive coverage in the central Arizona area, where snowmelt can occur rapidly, would ideally have to be of the order of one week or less. In the southern Sierras, aerial surveys are normally conducted bi-weekly; this, in that area a repetitive rate of coverage of the order of one week appears to be sufficient (allowing for the possibility of some data being cloud obscured).

The user agencies (and individuals) that are involved in the collection and use of snow data in the areas of the test sites being investigated are listed below:

1. Salt River Project
   Phoenix, Arizona

   Mr. William Warskow
   Watershed Specialist

2. Army Corps of Engineers
   Sacramento, California

   Mr. Richard Neal
   Chief Hydrologist

3. National Weather Service
   River Forecast Center
   Sacramento, California

   Mr. Robert J. C. Burnash
   Hydrologist in Charge

4. Department of Water Resources
   State of California
   Sacramento, California

   Mr. A. J. Brown
   Snow Surveys and Water Supply Forecasting Section

5. Army Corps of Engineers
   Seattle, Washington

   Mr. Norman J. MacDonald
   Chief Hydrologist

6. National Weather Service
   River Forecast Center
   Portland, Oregon

   Mr. Vale Schmerhorn
   Hydrologist in Charge

3. NEW TECHNOLOGY

No new technology has been developed during the second six-month period of the subject contract.

4. PROGRAM FOR NEXT REPORTING PERIOD

During the next reporting period, the investigation of the application of ERTS data for snow mapping will be concluded. The sample of ERTS black and white imagery is now considered to be essentially complete; imagery for the Arizona test site has been received through the entire snowmelt period, and imagery for the southern Sierra Nevada and Columbia Basin test sites has been received through most of the snowmelt season. Further work with the black and white data, therefore, will concentrate on completing the analyses already undertaken. Included will be completing the comparative analysis of ERTS and ERAP aircraft data to determine more exactly the scale of the snow features that can be detected at the ERTS resolution and the reexamination of cases in which a significant discrepancy was found between the snow extent mapped from ERTS imagery and that depicted on aerial survey snow charts.

It is anticipated that the sample of ERTS color composite data will be received early in the next reporting period. When these color composite transparancies are acquired, they will be examined to determine whether color products can be useful for snow mapping and, in particular, for snow detection in forested areas. The Black Hills area in the Missouri River Basin, where forested and non-forested terrain are sharply delineated, will be carefully examined in this regard. The initial examination of two color transparancies for the Arizona test site indicates that color products may have some advantages for snow detection and mapping. In the color transparancies, water features such as lakes, reservoirs, and rivers can be more readily identified, as can vegetation areas and the location of the treeline. In forested areas, snow appears to be more discernible than it is in the single-band data products. Furthermore, in the color data, snow can be more easily distinguished from highly-reflective snowfree rock surfaces and can be mapped more easily in shadow areas.

5. CONCLUSIONS

Based on the results of the data analysis completed through this reporting period, it is concluded that the amount of information in ERTS imagery with practical application to snow mapping is substantial. Moreover, for two mountain areas in which snow hydrology is a major concern, the Salt-Verde Watershed in Arizona and the Southern Sierra Nevada in California, useful snow cover information could be derived from ERTS data on 70 to 80% of the cycles during the past winter and spring seasons. Thus, in these two areas, cloud obscuration does not appear to be a serious deterrent to the use of satellite data for snow survey.

The results of the analysis of ERTS imagery for the Arizona and California test sites indicate that the extent of the mountain snowpacks can be mapped from ERTS data in more detail than is depicted in aerial survey snow charts. In the Salt-Verde Watershed, the agreement between the percentage of the area snow covered as measured from the ERTS data and from aerial survey charts is generally well within 10%. In nearly all of the areas in which greater discrepancies occur, the differences can be explained by changes in snow cover during the interval between the two observations. In the southern Sierra Nevada, the agreement between ERTS data and aerial survey charts is of the order of 5% in all cases, except for the Kaweah Basin on one date.

In addition to comparative analysis with aerial snow charts, the ERTS data have also been compared with high-altitude aircraft photography provided by the NASA/ARC Earth Resources Aircraft Project (ERAP). The ERAP data have provided an excellent source of correlative information. The results of the comparative analysis indicate that although small details in the snowline that cannot be detected in the ERTS data can be mapped from the higher-resolution aircraft data, the boundaries of the areas of significant snow cover can be mapped as accurately from the ERTS imagery as from the aircraft photography.

6. RECOMMENDATIONS

Specific recommendations will be included in the final report to be prepared during the next reporting period.